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ADDENDUM TO FINAL REPORT

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EFFICIENT HIGH POWER, SOLID STATE AMPLIFIER FOR EHF COMMUNICATIONS

28 March 1994

Period of Performance:

August 1, 1993 to March 31, 1994

Rockwell International
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PHASE II
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EFFICIENT HIGH POWER, SOLID STATE AMPLIFIER FOR EHF COMMUNICATIONS

28 March 1994

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NASA SATELLITE COMMUNICATIONS APPLICATION RESEARCH (SCAR)

PHASE II

ADDENDUM TO FINAL REPORT

1.0 SCOPE

This document is an addendum to the **NASA Satellite Communications Application Research (SCAR) Phase II Final Report**, "Efficient High Power, Solid State Amplifier for EHF Communications." This report describes the work performed from August 1, 1993, to March 11, 1994, under contract number NASW-4513.

During this reporting period an array of transistor amplifiers was repaired by replacing all MMIC amplifier chips. The amplifier array was then tested using three different feedhorn configurations. Descriptions, procedures, and results of this testing are presented in this report, and conclusions are drawn based on the test results obtained.

2.0 INTRODUCTION

2.1 Background

This effort addresses the need for high-power extremely high frequency (EHF) amplifiers exhibiting improved performance over components using current technology. High-power amplification is obtained using a unique orthomode spatial power combiner (OSPC) to (1) combine amplified output waves from a two-dimensional array of MMIC amplifiers and (2) isolate the output waves from the input signals.

In Phase I of the program the high-efficiency performance of a passive OSPC was demonstrated by building a proof-of-concept model and by performing measurements to determine its efficiency. The OSPC was designed, built, and tested for operation at 17 GHz. It combined the output signals from a 69-element passive array. The OSPC employed a longitudinally-slotted feedhorn and a 3-piece dielectric lens to produce a uniform phase on the array.

In Phase II of the program a new longitudinally-slotted feedhorn and an active array of MMIC amplifiers were designed, fabricated, and tested. During testing, an unfortunate biasing mishap occurred which burned out all of the devices in the array before the testing could be completed. The

Phase II final report documented the activities on the program up to that point, including the test results that were obtained prior to the biasing incident.

On the basis of a mutual agreement, the Phases II contract schedule was extended so that the MMIC devices could be replaced and the OSPC amplifier tests could be completed. This report presents the results of those tests that were conducted during the Phase II program extension, which was funded by Rockwell.

2.2 Technical Concept

The OSPC uses the principle of orthogonally-polarized electromagnetic waves to isolate signals entering and exiting a planar array of amplifiers. Illustrated in the schematic diagram of Figure 1, the OSPC amplifier is described briefly below. A more detailed description is provided in the Phase II Final Report.

A tapered horn is used to direct vertically-polarized fields to a planar array of amplifiers. Orthogonally-polarized radiating elements on the array receive a vertically-polarized wave and convert it to quasi-transverse electromagnetic (TEM) fields on microstrip lines on the array board. The signals are amplified and sent to the horizontally-polarized port of the radiating element. The signals are re-transmitted back through the horn using horizontal polarization. An orthomode transducer on the throat of the horn separates and isolates the two orthogonal (vertically-polarized input and horizontally-polarized output) signals. Since the radio frequency (RF) energy enters and leaves the array on the same side, the back side of the array can be used for heat sinking and biasing. This approach makes the OSPC amplifier fully compatible with full-scale, monolithic microwave integrated circuit (MMIC) wafer integration. The array can be formed from one or more gallium arsenide (GaAs) MMIC wafers.

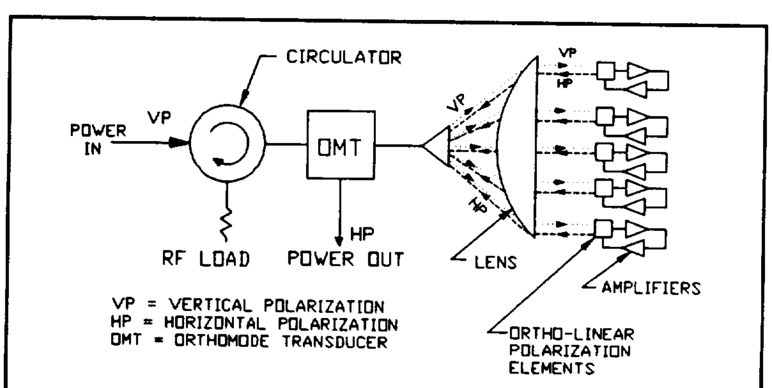

Figure 1. OSPC Schematic Diagram

2.3 Program Objectives

The purpose of this program was to demonstrate the feasibility of high-efficiency, high-power, EHF solid-state amplifiers that are smaller, lighter, more efficient, and less costly than existing traveling wave tube (TWT) amplifiers by combining the output power from up to several hundred solid-state amplifiers using a unique orthomode spatial power combiner (OSPC). The program consisted of two phases.

2.3.1 Phase I Objectives

The specific objective of the Phase I program was to verify conceptual feasibility of a passive OSPC by designing, fabricating, and testing a passive proof-of-concept model at 17 GHz (with amplifiers replaced by a direct connection) to achieve the performance goals listed in Table 1.

Table 1. Design Goals for the Phase I Passive OSPC

Parameter	Goal
Fractional Bandwidth	> 13%
20 dB Isolation	> 20 dB
Insertion Loss (2-way)	< 3 dB
VSWR	< 2:1

2.3.2 Phase II Objectives

The specific objective for Phase II was to verify conceptual feasibility of achieving power gain with an active OSPC amplifier by designing, fabricating, and testing a proof-of-concept amplifier model operating at Ku-band. The technical goal was to achieve over 5-watts output power by spatially combining power from a planar array of 69 monolithic microwave integrated circuit (MMIC) amplifier elements each having output power of 100 milliwatts. The horn structure was also to be optimized for field uniformity during Phase II of the program. The specific design goals for the 17-GHz OSPC amplifier are shown in Table 2.

Table 2. Design Goals for the Phase II OSPC Amplifier

Parameter	Goal
Fractional Bandwidth	≥ 10%
RF Amplifier Gain	≥ 10 dB
Number of Elements	= 69
Total Power Output	≥ 5 Watts
Input/Output VSWR	< 2:1

3.0 SUMMARY OF ACCOMPLISHMENTS

The following two sections summarize the results and accomplishments of the program during the previous program phases and during the current Phase II extension. A more detailed treatment of the accomplishments achieved in Phase I and Phase II is presented in their respective final reports.

3.1 Previous Accomplishments

During the course of Phase I the performance of a passive OSPC was demonstrated by building a proof-of-concept model and by performing measurements to determine its efficiency. The OSPC was designed, built, and tested for operation at 17 GHz. It combined the output signals from a 69-element passive array with a demonstrated combining efficiency of approximately 80%. The goals specified in Table 1 were achieved over a limited bandwidth.

In Phase II a new horn structure was designed along with a prototype amplifier circuit and an active MMIC amplifier array. The measured far-field patterns of the horn indicated that the horn produced near-uniform field distribution. The prototype amplifier circuit was fabricated and tested for gain and return loss. The amplifier circuit was characterized for RF output power as a function of input power and bias voltage. The amplifier circuit layout was then incorporated into an array pattern. The array was fabricated and assembled with the amplifier elements. The array was then assembled into the OSPC combiner horn and biased on. Observations from the output of the horn on a spectrum analyzer revealed that the OSPC amplifier oscillated at 16.4 GHz when biased to produce more than 3-dB gain with the Phase I horn.

The oscillations were attributed to higher-order mode resonances within the feedhorn. To verify this, the array was tested with a simulated space-fed feedhorn structure without enclosing walls. No oscillations were observed on the spectrum analyzer even when RF power was injected into the input port of the orthomode transducer with the array biased for low gain.

A biasing mishap occurred when tests were performed on the amplifier array. Before the response on the network analyzer could be recorded, the devices in the array burned out.

3.2 Current Reporting Period

A test plan was prepared and submitted for customer approval, along with a proposal to repair the damaged array. Subsequent to customer approval, the array was repaired by replacing the 69 MMIC amplifiers in the array. The array was tested for gain, power, and oscillations with three different feedhorn configurations: (1) a simulated space-fed feedhorn, (2) an absorber-lined Phase I feedhorn, and (3) the Phase II OSPC amplifier feedhorn.

The simulated space-fed feedhorn amplifier test demonstrated that the array produces over 10-dB gain with this feedhorn. Positive gain was achieved in excess of a 1-GHz bandwidth. Oscillations occurred at high gain levels due to higher-order mode resonances that developed in the cavity between the lens and the array. These resonances were produced because the cavity was not lined with absorber as it would be in an actual space-fed feedhorn.

The absorber-lined feedhorn amplifier test demonstrated that the array produces up to 13-dB gain without incurring oscillations in this configuration. The measured gain of the array is in agreement with the 13 dB gain measured on the single prototype amplifiers on test blocks. The test also demonstrated that the absorber material could attenuate all higher-order modes and thus inhibit oscillations. The gain response was smooth, indicating the absence of higher-order mode resonances.

The Phase II OSPC oscillation test showed that the Phase II OSPC amplifier produces non-coherent oscillation across the 1-GHz bandwidth due to higher-order mode resonances. Because these higher modes are cut off in the orthomode transducer, power cannot propagate to the output port of the orthomode transducer. Since the oscillations are non-coherent and spread out across the band, the OSPC amplifier cannot be configured as an efficient injection-locked amplifier. This test demonstrated the need to suppress all waveguide mode propagation in the feedhorn.

The test results indicate that an OSPC amplifier designed with a new space-fed horn has the potential to function as a spatially-combined power amplifier. The tests helped to identify design problems and to generate solutions to improve the OSPC amplifier to achieve high efficiency, making it suitable for application as a solid-state amplifier for millimeter-wave applications.

Two design improvements to eliminate oscillations in the OSPC amplifier were identified and examined as a result of this program: (1) a new space-fed feedhorn that eliminates higher-order mode resonances in the feedhorn while providing uniform field distribution and (2) a new array circuit layout which reduces undesirable radiation and coupling. A preliminary design and performance analysis was performed on the new space-fed feedhorn. The analysis showed that the new design produces near uniform field distribution across the face of the array. Since the design uses absorber material to emulate free-space (instead of waveguide) propagation to establish the field distribution, the structure cannot generate higher-order modes which might otherwise cause oscillation. Hence, this design has the potential to enable the OSPC amplifier to achieve its intended design goals.

4.0 TECHNICAL ACCOMPLISHMENTS AND RESULTS

During this extended Phase II period of performance, the following tasks were accomplished. (1) A comprehensive test plan for the OSPC amplifier was developed. (2) OSPC amplifier hardware was refurbished: (a) MMIC amplifiers were purchased and installed in the array, and (b) the Phase I horn was modified to include absorbers on the walls. (3) Test equipment was set up and calibrated, and three RF tests were conducted in accordance with the test plan. (4) Data was compiled and analyzed, and the results obtained are reported herein.

4.1 Test Plan

A test plan was developed for characterizing OSPC amplifier; this test plan is included as Appendix A. The specific objective of the test plan was to provide data which would permit (1) the characterization of the SCAR Phase II OSPC amplifier for power, gain, and stabilization (oscillation) characteristics and (2) a determination of whether an absorber-lined horn could effectively prevent oscillation. The plan included three different test configurations: (1) a simulated space-fed amplifier gain test, (2) an absorber-lined feedhorn test, and (3) an Phase II OSPC oscillation test. Measurements included gain (measured on a network analyzer), RF power, and spectrum analysis.

4.2 Refurbishment

The amplifier array and the Phase I feedhorn were modified as follows: All MMIC amplifier chips in the array were replaced. To minimize device performance variations, the purchase order for the replacement chips included a specific requirement that all of the new chips originate from the same wafer. The Phase I horn, depicted in Figure 1 of Appendix A, was modified as follows: The longitudinal slots containing foam dielectric material at the mouth of the horn were machined off to form a smooth wall. Approximately two-thirds of the wall from the mouth to the throat of the horn was then lined with absorber material (Emerson and Cuming's ECCOSORB™ SF-16).

4.3 Testing

In accordance with the test plan, the following three tests were conducted on the OSPC amplifier array: (1) the simulated space-fed amplifier gain test, (2) the absorber-lined feedhorn test, and (3) the Phase II OSPC oscillation test.

A list of the test equipment, manufacturer and model number, identification number, and calibration data is presented in Table 3.

Table 3. Test Equipment Traceability

Ref. No.	Equipment	Manufacturer	Model	ID Number	Calibration Number	Calibration Date
1	Network Analyzer	Hewlett Packard	8510B	NO188556	83068E	6/4/93
2	Power Supply	Hewlett Packard	6024A	NO578137	40669B	2/15/94
3	Digital Multimeter	Data Precision	1351	NO890440	25900B	2/14/94
4	Spectrum Analyzer	Hewlett Packard	8566B	NO367990	03234B	1/31/94
5	Scope Camera	Tektronix	C-5C	NO890194	N/A	N/A
6	RF Power Meter	Hewlett Packard	436A	NO183922	25897B	2/15/94
7	Power Meter Sensor	Hewlett Packard	8481H	NO313673	25897B	2/15/94
8	RF Signal Source	Wiltron	6647	NO388776	20567B	2/15/94

4.3.1 Simulated Space-Fed Amplifier Gain Test

4.3.1.1 Purpose

The purpose of this test was to demonstrate the validity of the orthomode spatial power combiner concept by measuring the gain of the OSPC Amplifier array.

4.3.1.2 Simulated Space-Fed Amplifier Configuration

The simulated space-fed amplifier consisted of a 69-element active amplifier array, a parasitic patch array, and a three-piece dielectric lens, all of which were assembled using the final (aft) section of the Phase II orthomode spatial power combiner. A ½-inch thick, toroidal ring was used to hold the lens in place. The orthomode transducer was mounted on an absorber-lined metal plate which was suspended approximately eight inches above the array by four threaded metal rods on the circumference of the array. The four rods also secured a phenolic ring to the final section of the Phase II horn. A waveguide circulator was attached at both the input and output ports of the orthomode transducer (OMT).

4.3.1.3 Approach

The OSPC Amplifier was configured as a simulated space-fed amplifier to allow gain measurements to be taken in the absence of horn-induced oscillations. The network analyzer was calibrated from 15.5 to 17.5 GHz in 10-MHz steps. An initial forward transmission (S21) measurement was made using a passive array for a reference. The passive array was then replaced with the active array.

Gain (referenced to the passive array) was measured at several incrementally increasing bias voltages, from 4.0 to 8.5 volts.

4.3.1.4 Test Procedure

The measurements were made in accordance with the test procedure documented in Section 7.1.3 of the test plan. For reference, the procedural steps specified in the test plan are shown bracketed in the next section, (e.g., [1]).

4.3.1.5 Test Results

The HP 8510B automatic network analyzer was calibrated with full four-port error correction over the frequency from 15.5 to 17.5 GHz in steps of 10 MHz using APC-3.5 connectors [1].

The simulated space-fed amplifier configuration was assembled as described in paragraph 4.3.1.2, above, using the passive feed-through array [2]. The network analyzer was then used to measure the gain response of this configuration [3]. Figure 2 shows a plot of the S21 reference measurement made with the passive array. The 0.5-inch diameter opening on the dual-polarized port of the orthomode transducer served as the radiating element. Since no horn was used (low directivity), the 2-way spillover loss was quite high (25 dB), as shown in Figure 2. The wave-like response of the curve is caused by reflections between the array and the unmatched waveguide opening of the orthomode transducer. Subsequent gain measurements were referenced to a linear fit of the S21 transmission response. This referencing method was employed to eliminate gain ripples caused by mismatch, since the phase length of the active array is known to differ from that of the passive array.

The passive array was replaced by the active amplifier array, and the simulated space-fed amplifier was reconnected to the same ports of the network analyzer as previously [4]. With the voltage supply current limit set at 10.5 amperes [5], the response was measured on the network analyzer with the array biased at 6.0 volts and 9.5 amperes [6].

Figure 3 shows the absolute S21 measurement prior to normalizing to the reference measurement. The plots provided in Figures 4, 5, and 6 show the gain of the simulated space-fed amplifier biased at 4.0, 4.5, and 6.0 volts respectively, with the gain measurements being normalized to the reference measurement of the passive array.

The bias voltage was then increased to 8.0 volts, corresponding to the current limit of 10.5 amperes [7]. The response was measured on the network analyzer and normalized to the reference measurement of the passive array [8]. This data is plotted in Figure 7.

The jagged response lines shown in Figure 6 and Figure 7 are caused by higher-order modes and oscillations in the array. The network analyzer cannot always phase lock to the correct signal in the presence of oscillations. Hence, some of the points in these plots appear jagged.

The output of the active simulated space-fed amplifier was connected to the spectrum analyzer. The frequency span on the spectrum analyzer was set from 15.5 to 17.5 GHz. Photographs were taken of the spectrum analyzer display with the bias voltage set at 4.0, 4.5, 6.0, and 8.0 volts.

No evidence of oscillation was observed with the array biased at 4.0 volts, as shown in Figure 8. At a bias voltage of 4.5 volts (Figure 9), the array was just starting to oscillate. The amplifiers in the array reached their highest gain and maximum amount of oscillation at 6.0 volts, as shown in Figure 10. Figure 11 shows the spectrum with the array biased at 8.0 volts. This actually produced less gain at low input signal levels than it did at 6.0 volts. Hence, the amount of oscillation apparent in Figure 11 is not as great as that observed in Figure 10.

4.3.1.6 Test Conclusions

This test demonstrated several key points: (1) The simulated space-fed array produced over 10-dB gain. (2) Oscillations occurred only when the array was biased such that the gain exceeded 10 dB. (3) Unlike the response of the single prototype circuit, the gain response of the array was not flat. (4) Without the feed and support plate, oscillations did not occur even with 13-dB amplifier gain.

The ripple in both the reference and gain measurements was caused by the reflection between the open end of the orthomode transducer (which was not matched to free space) and the array.

The simulated space-fed amplifier used in these tests only approximated an space-fed amplifier. In the configuration used, the cavity between the lens and the array was not loaded with absorber to remove any cavity resonances. In an actual space-fed configuration, this cavity would be loaded with absorber to avoid higher-order mode resonances that cause oscillation.

The conclusion from this is that amplification can be achieved without oscillations with a properly designed space-fed amplifier structure.

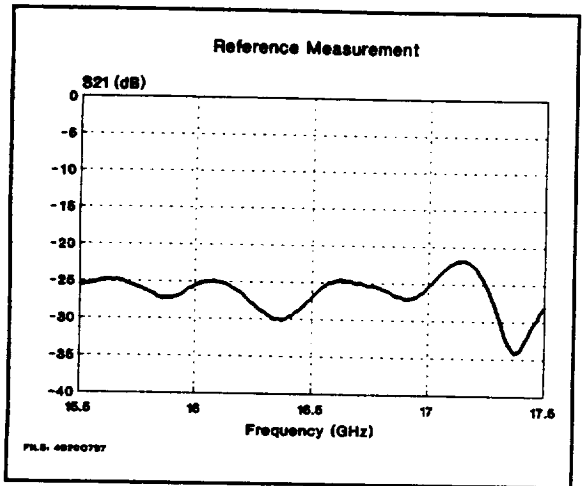

Figure 2. S21 with Passive Array

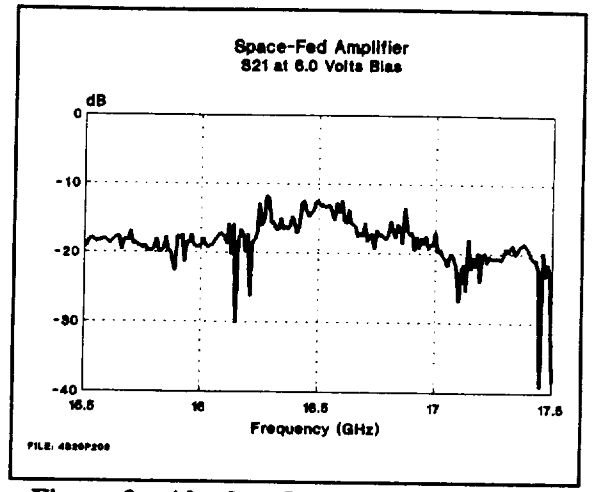

Figure 3. Absolute Response at 6.0 Volts

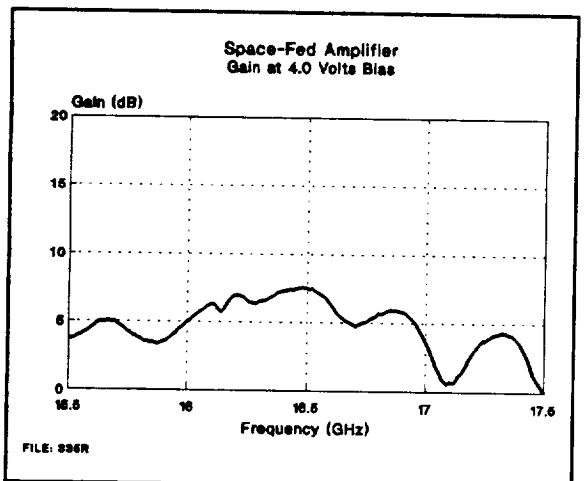

Figure 4. Gain of Active Array at 4.0 Volts

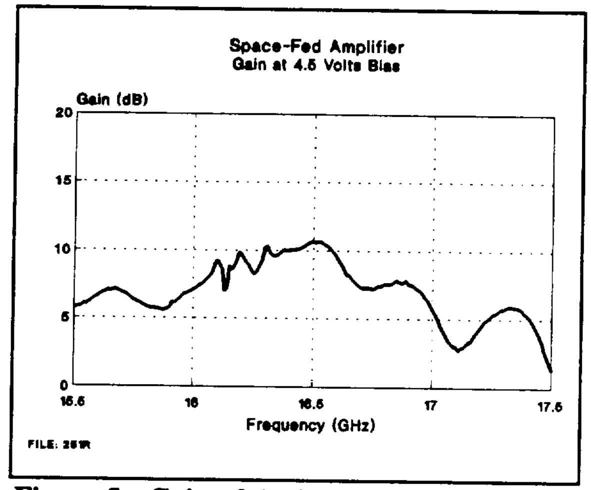

Figure 5. Gain of Active Array at 4.5 Volts

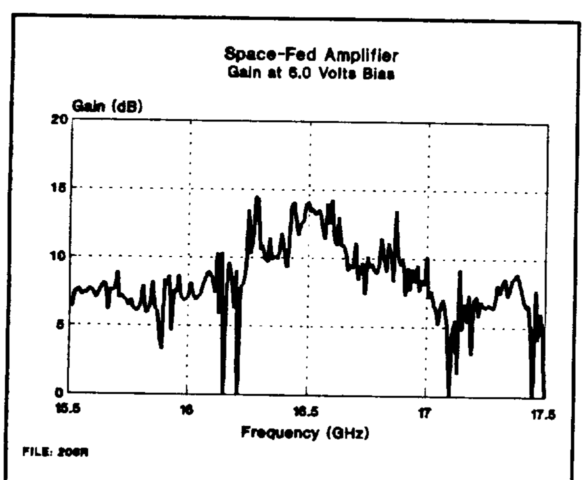

Figure 6. Gain of Active Array at 6.0 Volts

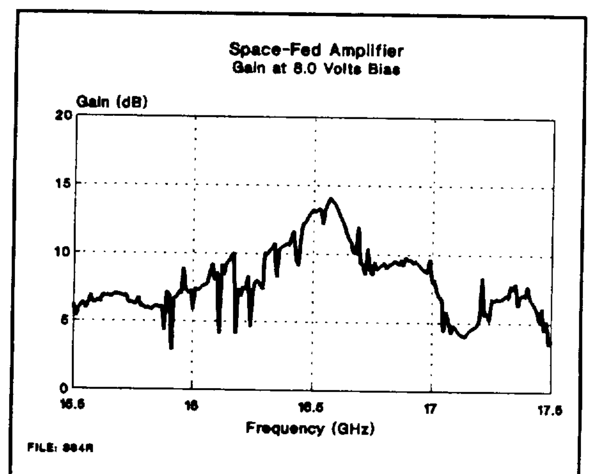

Figure 7. Gain of Active Array at 8.0 Volts

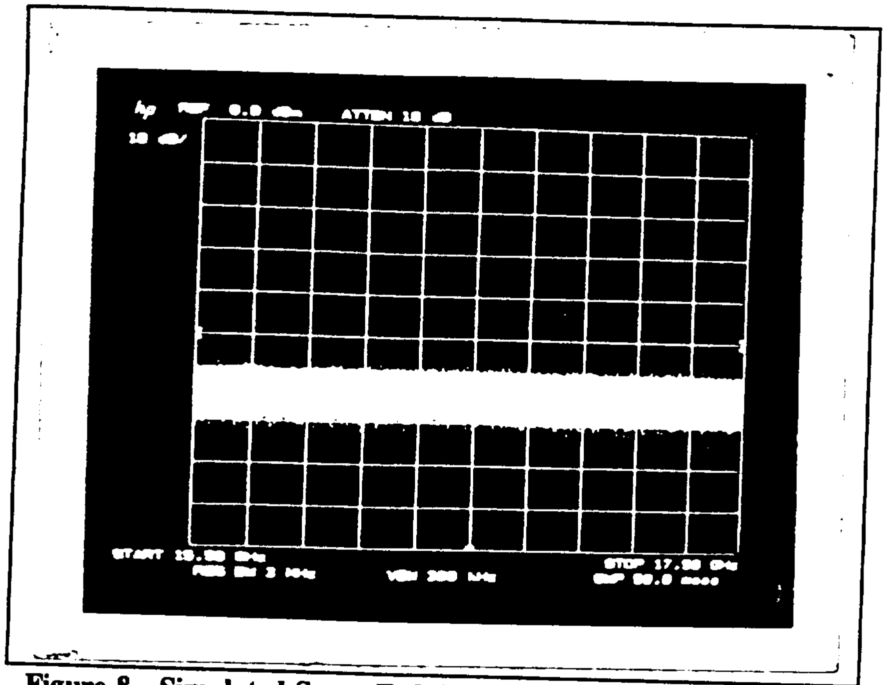

Figure 8. Simulated Space-Fed Amplifier Spectrum at 4.0 Volts

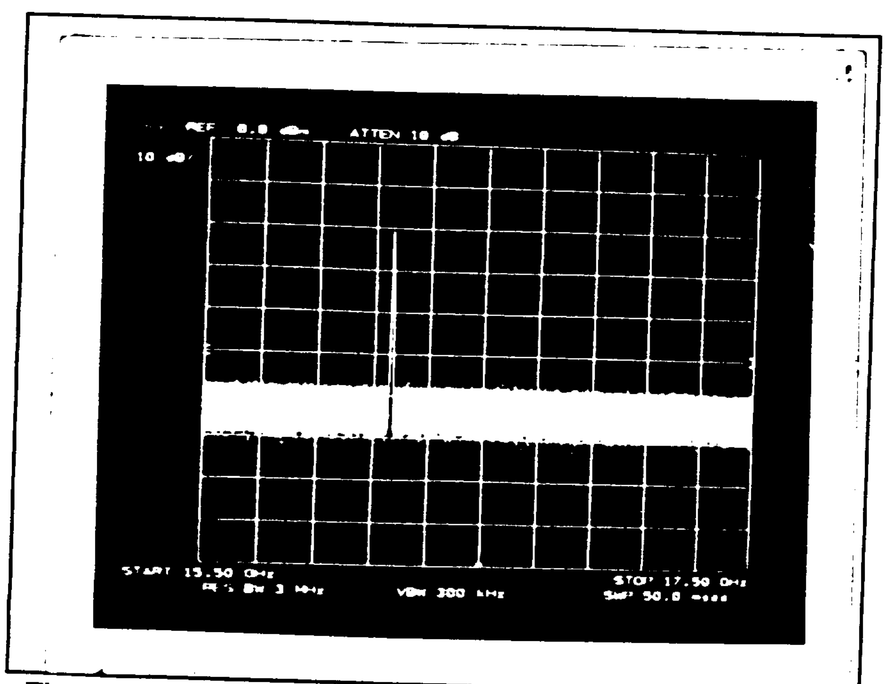

Figure 9. Simulated Space-Fed Amplifier Spectrum at 4.5 Volts

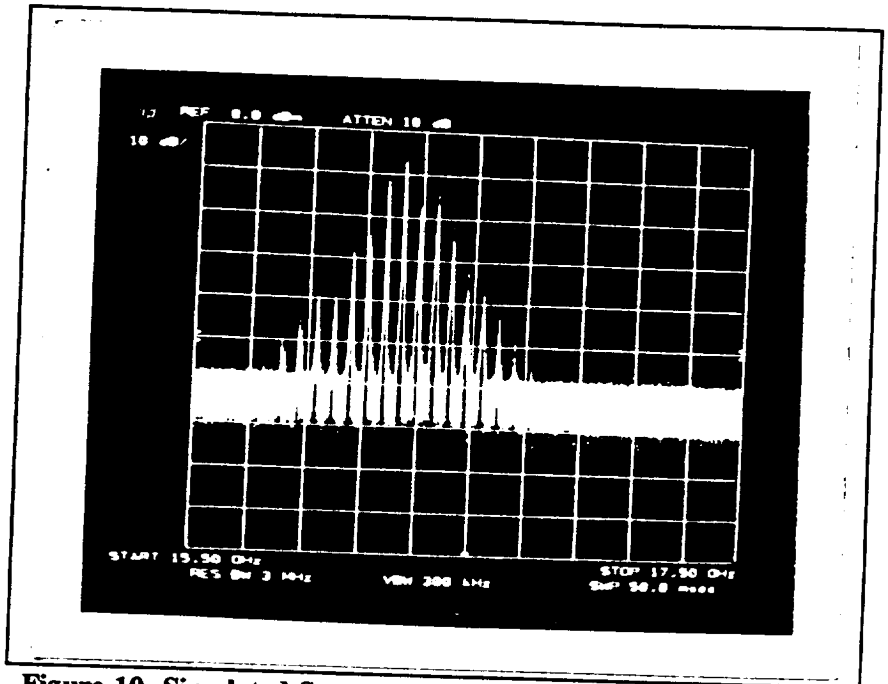

Figure 10. Simulated Space-Fed Amplifier Spectrum at 6.0 Volts

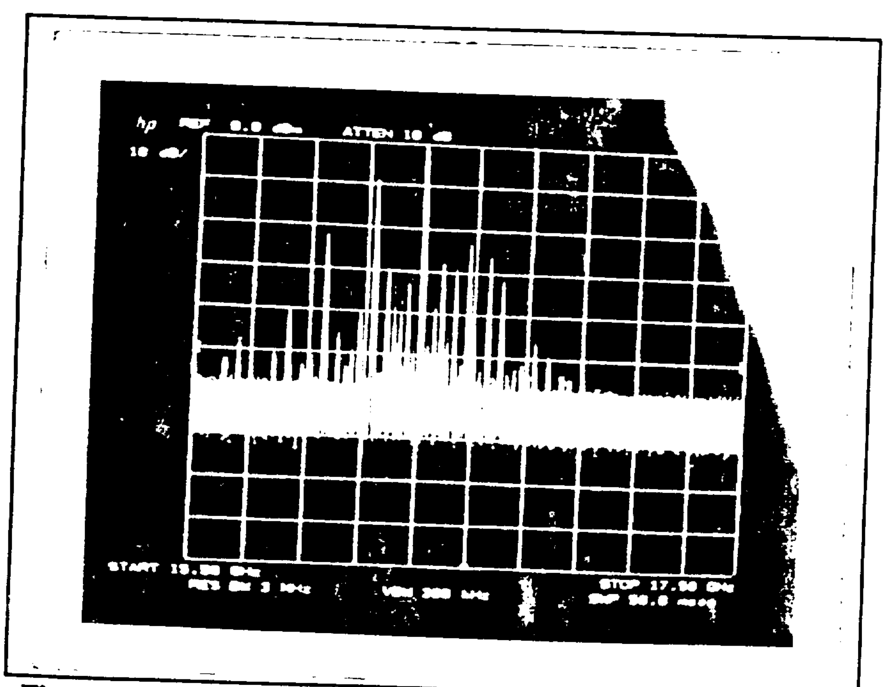

Figure 11. Simulated Space-Fed Amplifier Spectrum at 8.0 Volts

4.3.2 Absorber-Lined Feedhorn Test

4.3.2.1 Purpose

The purpose of this test was to demonstrate the validity of using absorber material in the feedhorn to simulate a free-space environment, void of higher-order mode resonances. If the feedhorn design were the major cause of oscillation, then lining the horn with absorber material should eliminate higher-order mode resonances and the oscillations caused by these resonances. In this case, the OSPC amplifier array should produce gain without oscillations.

4.3.2.2 Absorber-Lined Feedhorn Configuration

The Phase I horn, depicted in Figure 1 in the test plan presented in Appendix A, was modified as follows: The longitudinal slots containing foam dielectric material at the mouth of the horn were machined off to form a smooth wall. Approximately two-thirds of the wall from the mouth to the throat of the horn were then lined with absorber material (Emerson and Cuming's ECCOSORB™ SF-16). The three-piece dielectric lens and the active and parasitic patch arrays were assembled to form an OSPC amplifier.

4.3.2.3 Approach

The OSPC Amplifier was configured using the absorber-lined Phase I amplifier described above. The bias voltage was raised slowly; at the same time the spectrum analyzer was continuously monitored for signs of oscillation. If oscillations occurred, the voltage and current levels were to be recorded and the spectrum analyzer display was to be photographed, first at the voltage level corresponding to the onset of the oscillation and then at a higher bias. If no oscillations occurred, a photograph of the spectrum analyzer was to be taken to demonstrate the absence of oscillation. If oscillations did not occur, the gain of the amplifier with both the active and passive arrays was to be measured on the HP 8510B automatic network analyzer (ANA).

4.3.2.4 Test Procedure

The measurements were made in accordance with the test procedure documented in Section 7.2.3 of the test plan. For reference, procedural steps specified in the test plan are shown bracketed in the next section, (e.g., [1]).

4.3.2.5 Test Results

The absorber-lined feedhorn assembly was configured as described above and the output port of the orthomode transducer (OMT) was connected to the spectrum analyzer. The input port of the OMT was terminated with a matched load [1]. Waveguide circulators were placed on both the input and output ports. The frequency range of the spectrum analyzer was set to cover 15.5 to 17.5 GHz [2]. The current limit on the voltage supply was set to 10.5 amperes. The bias voltage to the array was slowly raised to 8.0 volts while the spectrum analyzer display was observed for oscillations [3].

Oscillations were observed when the bias voltage reached 5.0 volts (onset of oscillation) at a current reading of 9.9 amperes [4,5]. Figure 12 is a photograph of the output at the onset of oscillation. The bias voltage was then raised to 8 volts with a current of 10.5 amperes [6]. Figure 13 is a photograph of the spectrum analyzer display with the amplifier bias set to 8.0 volts.

Since the bias could be set high enough to produce excessive gain (over 13 dB at 4.5 volts), the following tests were run on the absorber-lined feedhorn at the reduced bias level of 4.5 volts.

The photograph of the spectrum analyzer display in Figure 14 shows no oscillation with the array biased at 4.5 volts and drawing 9.8 amperes of current [7]. The termination was removed from the input port of the OMT and replaced by a coaxial lead from the RF signal source. The signal level from the source was set to +11 dBm at 16.5 GHz. With the amplifier still biased at 4.5 volts and drawing 9.8 amperes, the frequency was slowly swept from 15.5 to 18.0 GHz [8]. No oscillations were observed in the presence of the swept injected RF signal [9]. Figure 15 is a photograph of the spectrum analyzer display with the RF source set at a fixed frequency of 16.5 GHz.

The HP 8510B automatic network analyzer was recalibrated using full four-port error correction over the frequency range from 15.5 to 17.5 GHz in steps of 10 MHz using APC-3.5 connectors [10]. For the initial reference measurement, the active array in the absorber-lined feedhorn was replaced with the passive feed-through array. With waveguide circulators attached to the input and output ports of the orthomode transducer (OMT), the amplifier was connected to the network analyzer [11]. The S21 response of the absorber-lined feedhorn with the passive array was measured and stored and is presented in Figure 16. Subsequent gain measurements were referenced to a linear fit of the S21 transmission response. This referencing method was employed to eliminate gain ripples caused by mismatch, since the phase length of the active array is known to differ from that of the passive array.

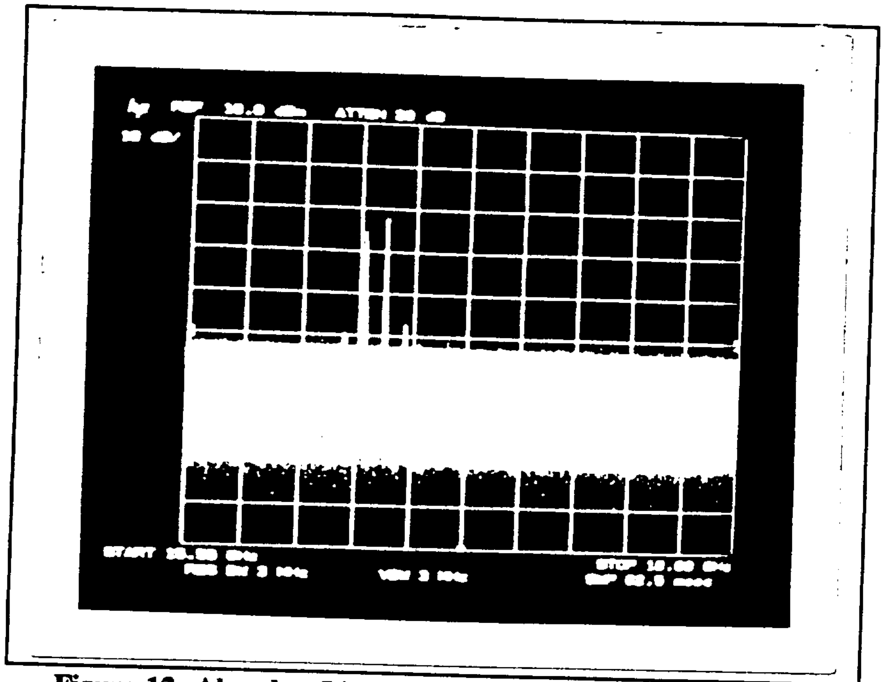

Figure 12. Absorber-Lined Amplifier Spectrum at 5.0 Volts

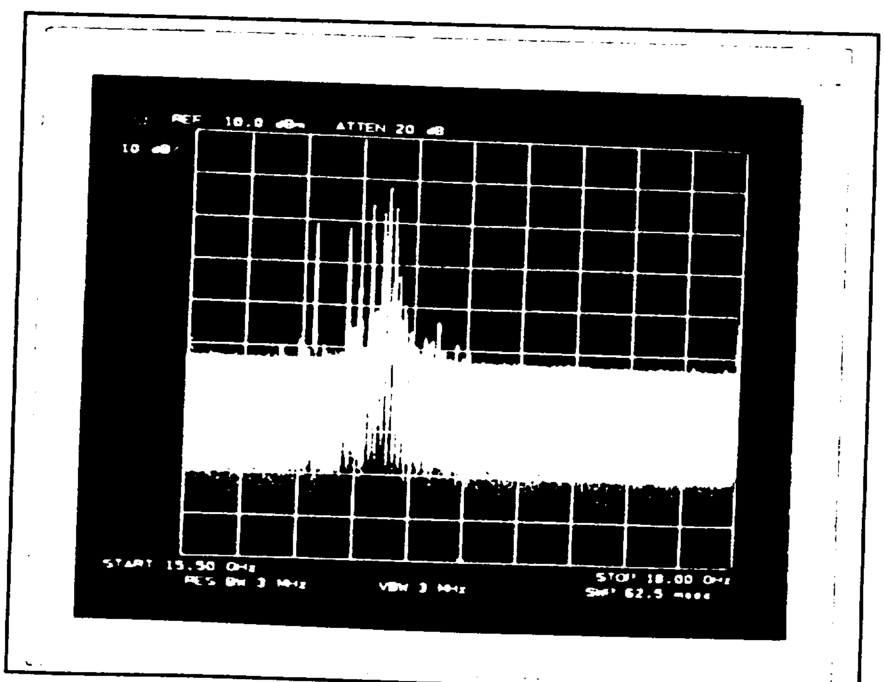

Figure 13. Absorber-Lined Amplifier Spectrum at 8.0 Volts

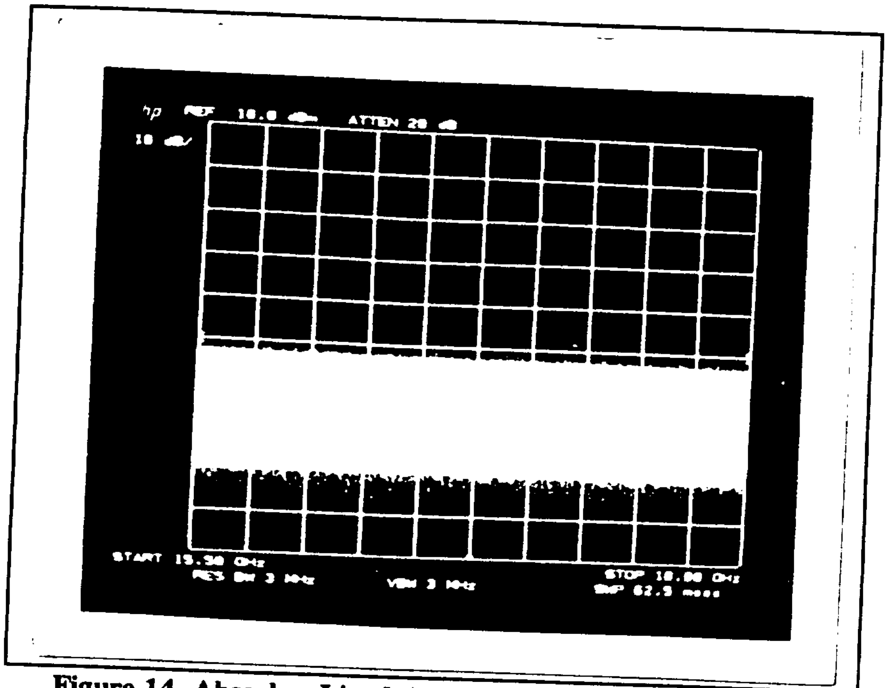

Figure 14. Absorber-Lined Amplifier Spectrum at 4.5 Volts

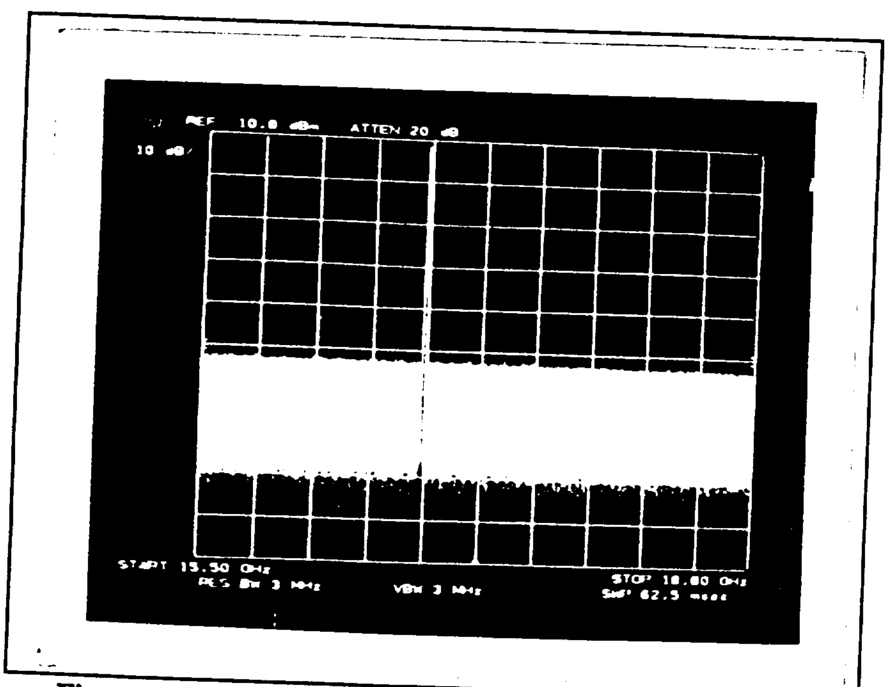

Figure 15. Amplifier Biased 4.5 Volts with 16.5-GHz Input

The passive array in the absorber-lined feedhorn was replaced with the active amplifier array [13]. The current limit on the voltage supply was set to 10.5 amperes and the bias voltage was raised from zero to 4.5 volts [14].

The S21 response was measured on the network analyzer over the calibrated frequency range with the voltage set a 4.5 volts and the array drawing 9.8 amperes [15]. Figure 17 shows a plot of the resulting response. The plots provided in Figures 18, 19, and 20 show the gain of the absorber-lined amplifier biased at 3.5, 4.0, and 4.5 volts, respectively, with the gain measurements normalized to the reference measurement of the passive array [16].

The bias voltage was raised to 7.5 volts at 10.2 amperes and the response was measured on the network analyzer, then normalized to the reference measurement [17, 18]. The plot of the normalized response is presented in Figure 21.

4.3.2.6 Test Conclusions

The absorber-lined feedhorn amplifier produced up to 13-dB gain without incurring oscillations. This agrees closely with the maximum 13-dB gain obtained with the single prototype amplifier circuit shown in Figure 22. Higher-order-mode-induced resonances were attenuated by the absorber material lining the walls of the horn. The gain response taken over the frequency band was smooth, free of higher-order mode resonances. Reflections caused by field mismatch produced positive feedback, which raised the gain up to 15 dB at certain frequencies. Only under these extreme conditions (gain >15 dB) did oscillations occur. With gain greater than 15 dB, coupling within the array could cause oscillation to occur, independent of which feedhorn is being used. Without feedback, this type of amplifier will not produce over 13-dB gain.

As shown Figure 16, the absorber-lined amplifier with the passive array had nominal loss of 15 dB with a maximum ripple of 5 dB. Two factors contributed to the loss. (1) The horn produced a dominant TE_{11}-mode in the throat of the feedhorn. In this mode the fields are zero at the walls. Because the fields are non-uniform at the array, high field-mismatch losses result when the polarizations of segmented fields across the array are rotated 90 degrees. Some of the mismatched fields are attenuated in the absorber material lining the walls, and some are reflected back to the amplifier array. These reflected signals caused the ripple in the gain response of the active array. (2) The absorber material also attenuated the desired dominant TE_{11}-mode fields.

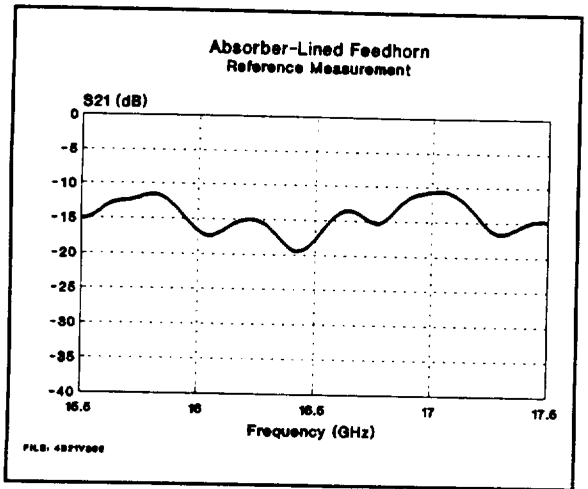

Figure 16. S21 with Passive Array

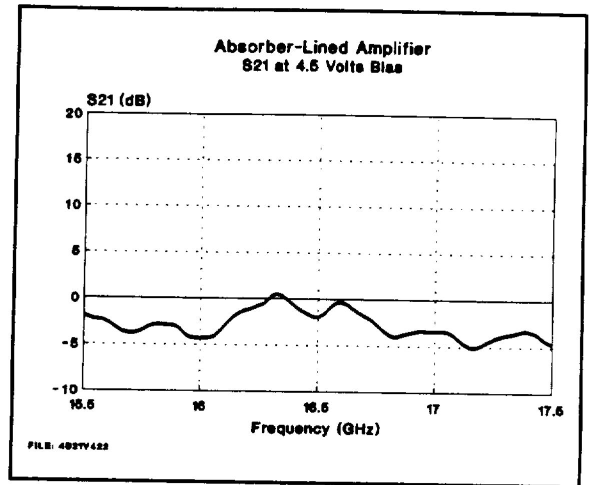

Figure 17. Absolute Response at 4.5 Volts

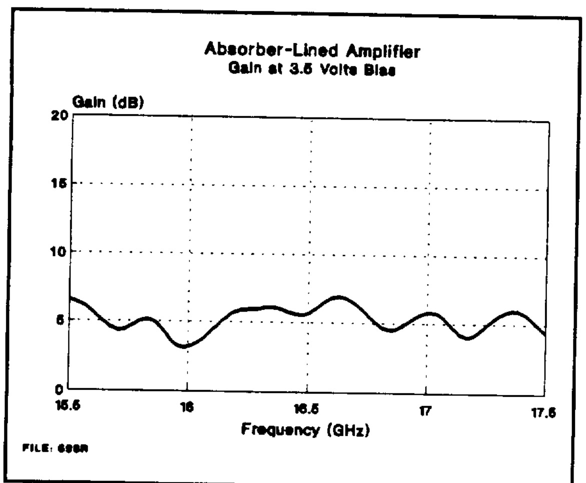

Figure 18. Array Gain at 3.5 Volts

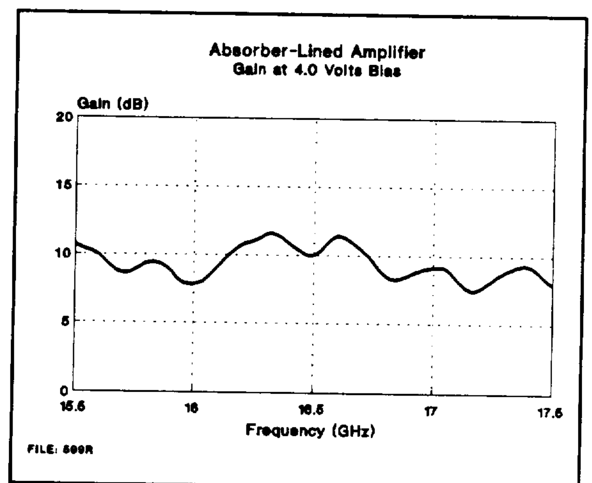

Figure 19. Array Gain at 4.0 Volts

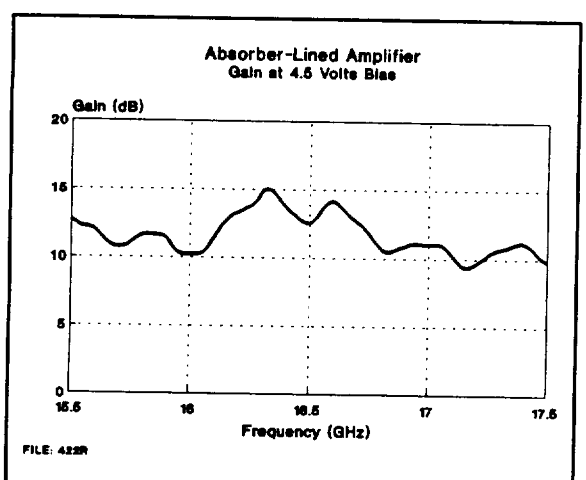

Figure 20. Array Gain at 4.5 Volts

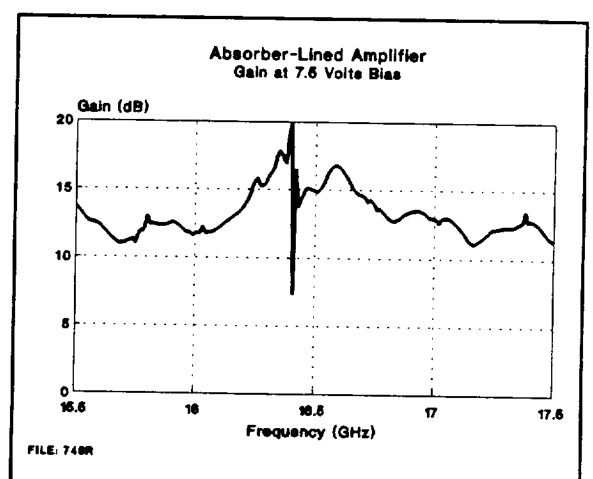

Figure 21. Array Gain at 7.5 Volts

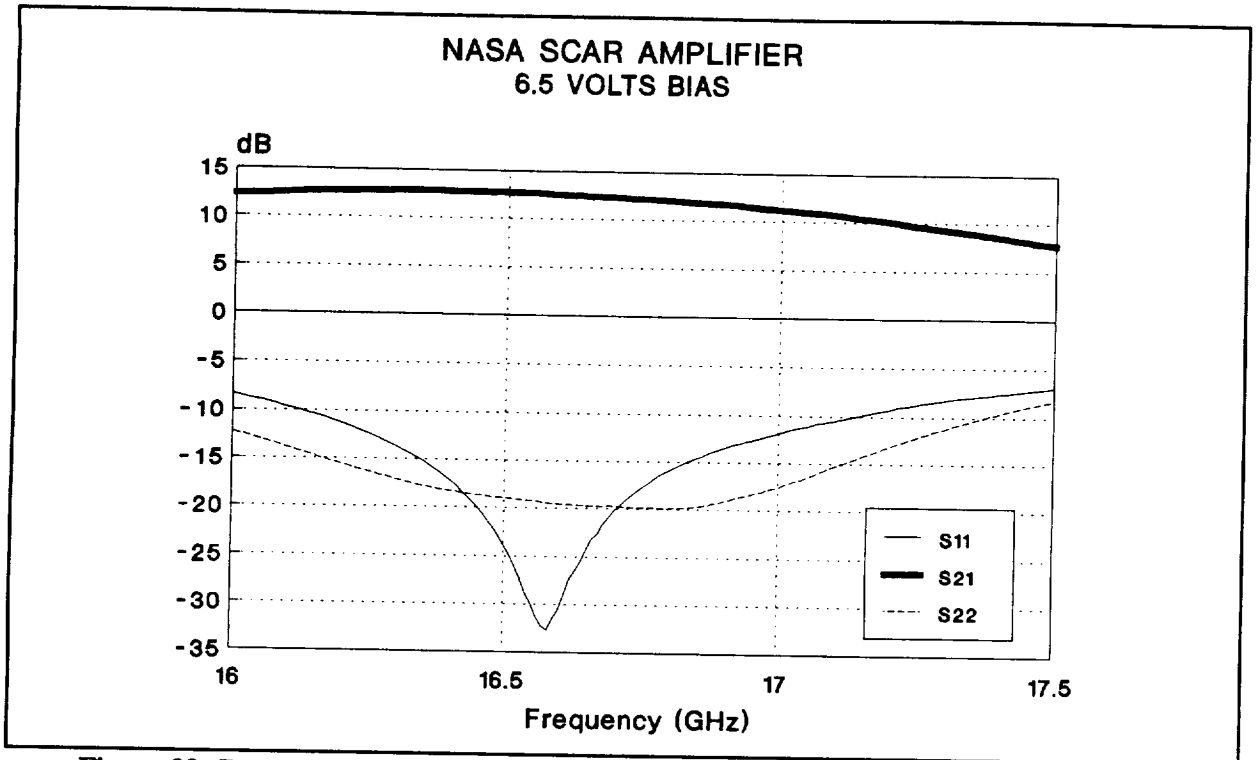

Figure 22. Response of a Single Prototype Amplifier on a Test Block at 6.5-Volt Bias.

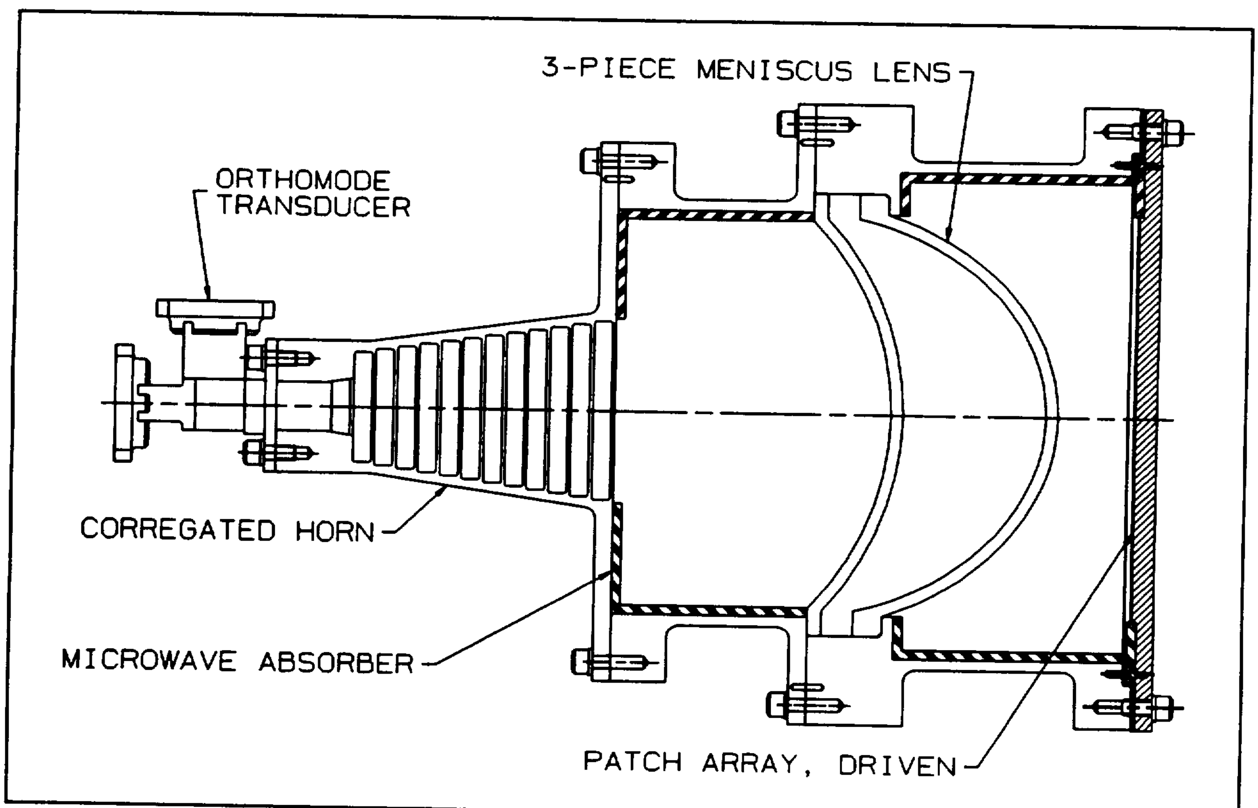

Figure 23. Space-Fed Feedhorn with Corrugated Horn and Meniscus Lens

The tests performed with the absorber-lined feedhorn demonstrated that the orthomode spatial power combiner can combine power from a two-dimensional, ortho-linear array of amplifiers without higher-order-mode-induced oscillations. They also demonstrated that absorber material can be used to attenuate higher-order modes.

Equipped with a corrugated horn and meniscus lens, the space-fed feedhorn concept shown in Figure 23 is designed to produce uniform field distribution across the face of the array without attenuating the desired fields in the absorber material. The transverse corrugated horn combines the dominant TE_{11}-mode with a TM_{11}-mode to produce a hybrid mode which has rotational symmetry and polarization orthogonality. The taper of the horn aperture is designed to radiate a field pattern across the lens with minimum spillover loss (<0.5 dB). The 3-piece meniscus lens converts the radiated field pattern into a uniform amplitude and phase distribution across the face of the aperture. Field mismatch losses (and reflections caused by field mismatches) are minimal (under 0.5 dB in each direction). The one-way loss in this structure is estimated to be less than 1.25 dB.

The space-fed feedhorn design shown in Figure 23 is a more efficient implementation of the space-fed approach that was approximated by the absorber-lined feedhorn employed during this test. The results of the absorber-lined feedhorn test have demonstrated that the space-fed approach is indeed viable.

4.3.3 OSPC Oscillation Test

4.3.3.1 Purpose

The purpose of this test was to characterize the oscillation of the OSPC amplifier by recording its oscillation spectrum, measuring the output power, and determining injection-locking properties.

4.3.3.2 OSPC Amplifier Configuration

As shown in Figure 2 of the test plan, the Phase II OSPC Amplifier consisted of the orthomode transducer (OMT), the Phase II longitudinally-slotted horn, the three-piece dielectric lens, the parasitic patch array, and the 69-element active amplifier array.

4.3.3.3 Approach

The assembly was configured using the Phase II OSPC amplifier as shown in the previous figure. A spectrum analyzer was used to observe the frequency spectrum of oscillations. Photographs were taken to record the spectrum analyzer display. Absolute power measurements were recorded using an RF power meter. An RF signal was injected into the OSPC amplifier, and the frequency and power level of this signal were varied to determine if the amplifier could be injection-locked.

4.3.3.4 Test Procedure

The measurements were made in accordance with the test procedure detailed in Section 7.3.3 of the test plan. For reference, the procedural steps specified in the test plan are shown bracketed in the next section, (e.g., [1]).

4.3.3.5 Test Results

The Phase II OSPC amplifier was configured as described above. Circulators were placed on both the input and output ports of the orthomode transducer (OMT). The input port of the input circulator was terminated with a waveguide load and the output port of the output circulator was connected to the spectrum analyzer [1]. The spectrum analyzer was set to cover the frequency range from 15.5 to 17.5 GHz [2].

The current limit on the power supply was adjusted for a maximum of 10.5 amperes and the supply voltage was set to zero volts [3]. The bias voltage to the array was slowly raised [4].

The first sign of oscillation occurred with the bias set at 3.39 volts and the amplifier drawing 8.6 amperes of current. Figure 24 is a photograph of the spectrum analyzer display at first oscillation. The power meter was connected to the output port; however, the output power level was too low to be read on the power meter [5].

The bias voltage was slowly raised until multiple oscillations were visible on the spectrum analyzer; the bias voltage was then lowered until only a single oscillation was present. This occurred at a bias voltage of 3.77 volts and a current of 8.6 amperes [6]. A photograph of the spectrum analyzer display is shown in Figure 25. The measured power level was -2.62 dBm [7].

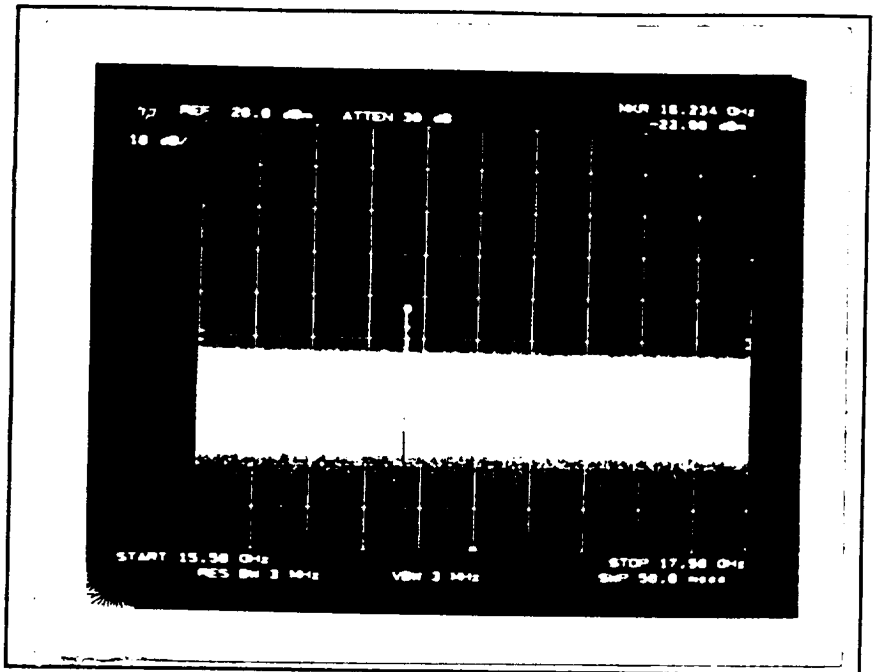

Figure 24. OSPC Amplifier at First Sign of Oscillation (3.39 Volts)

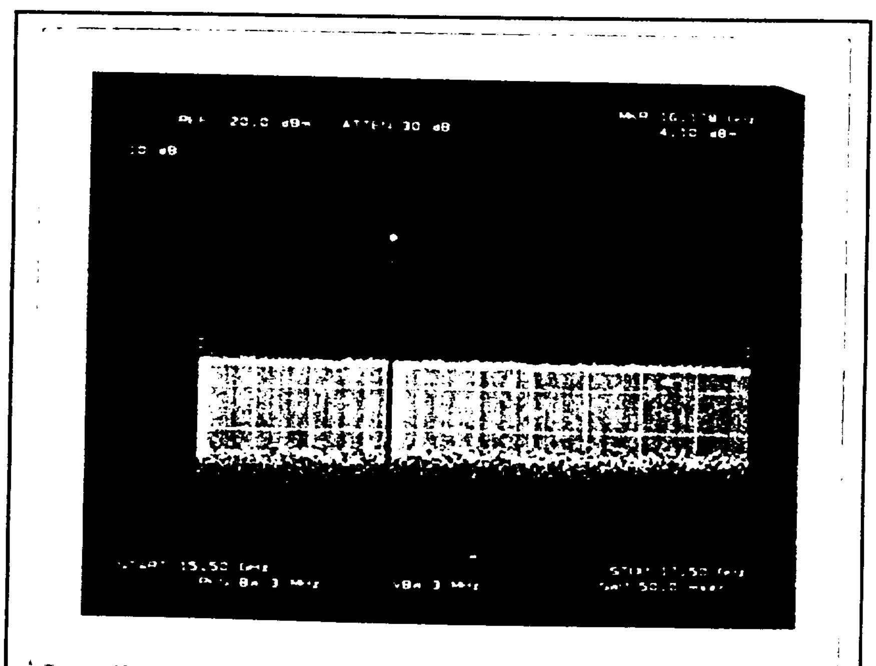

Figure 25. Maximum Bias (3.77 Volts) for a Single Oscillation

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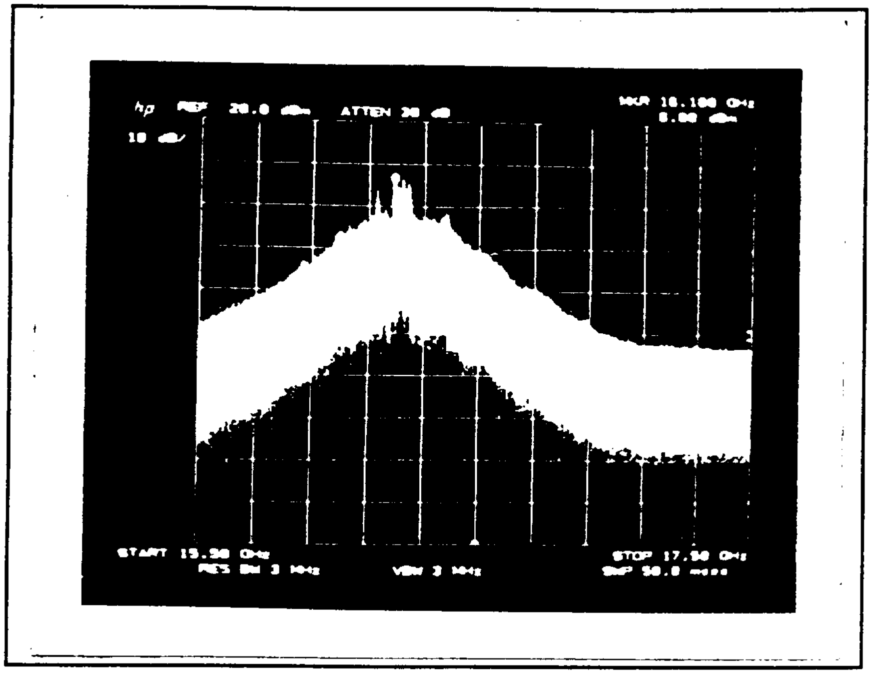

Figure 26. Amplifier Oscillation at Maximum Bias (7.6 Volts)

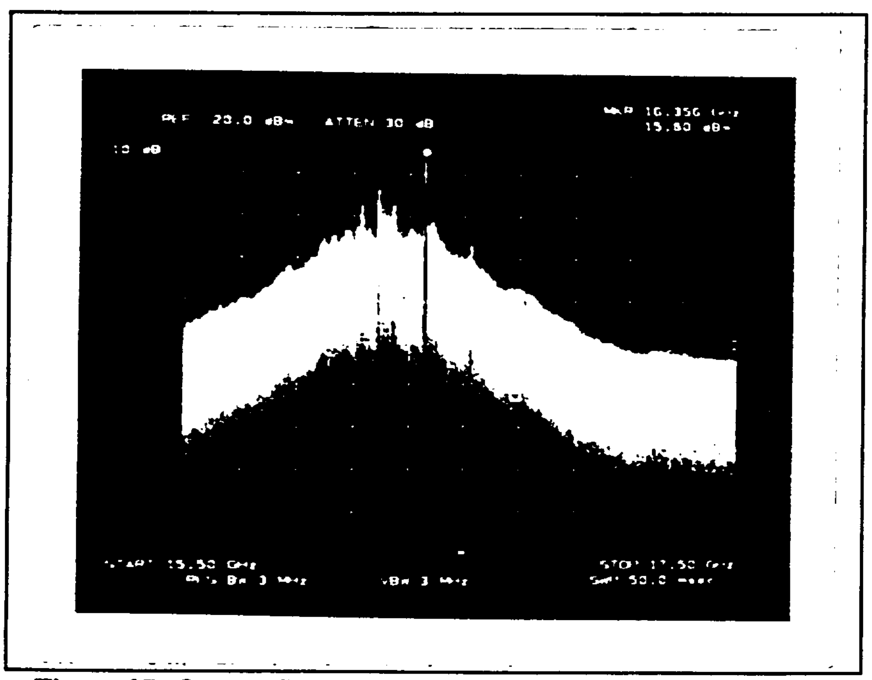

Figure 27. Output Spectrum at Full Bias with RF Input Signal

Since multiple oscillations occurred, the output port was reconnected to the spectrum analyzer and the bias level was raised to 7.6 volts, which was the maximum voltage allowed by the current limit (10.2 amperes) [8]. The oscillation output power was 13.9 dBm [9]. The spectrum analyzer display is shown in the photograph in Figure 26.

Since the amplifier did not have a stable, free-running oscillation mode, the injection-locked tests (steps 10 through 15 in the test procedure) could not be conducted. However, one additional test was conducted. With the OSPC amplifier biased at 7.0 volts and 10.2 amperes and an RF power level of 20.3 dBm injected at the input, the output power was measured to be 18.2 dBm. A photograph of the spectrum analyzer display is shown in Figure 27.

4.3.3.6 Test Conclusions

The active Phase II OSPC amplifier produced non-coherent oscillation across the band. Most of the output power from the amplifiers supported higher-order modes which could not be coupled out of the orthomode transducer. Hence the energy was converted to heat in the dielectric-filled slots along the walls of the horn and in the array base-plate. Since the oscillations were non-coherent and spread over the band, these results indicated that the OSPC Amplifier could not be used as an effective injection-locked oscillator.

The output power measured 18.2 dBm. Given the 6-dB 2-way loss of the passive array measured in Phase II and 0.5-dB loss for each circulator, the OSPC amplifier should produce about 24.3 dBm of output power with an input power of 20.3 dBm (assuming 11-dB gain).

The active array performs differently from the passive array in the horn structure because amplifiers are non-reciprocal devices. In the passive array, field mismatches at the output of the array are reflected back through the array to the input port. However, this cannot happen with an active array since the path in the array is unidirectional. Since the energy has to go somewhere, it sets up higher-order modes which proliferate in the cavity between the orthomode transducer and the array.

The conclusion from this is that, in addition to requiring uniform amplitude and phase distribution at the array, the OSPC amplifier requires a structure that does not support higher-order mode propagation. In the space-fed design, the amplifier array is surrounded by a non-reflective environment for all modes. Hence, the space-fed approach with the corrugated feedhorn and meniscus lens provides a viable approach for obtaining high-efficiency, spatially-combined power amplification without encountering higher-order mode resonances.

5.0 CONCLUSIONS

Although the OSPC amplifier did not achieve full success as a working power amplifier, the test results performed on it validated the basic OSPC amplifier concept. It provided significant data leading to an understanding of the concepts necessary to realize the full potential of a spatial power combining amplifier. The data obtained and achievements accomplished in both Phase I and Phase II of the SCAR program represent stepping stones of progress. The most salient of these are summarized below.

(1) The passive array horn built in Phase I of this program demonstrated that spatial power combining provides a highly efficient means of combining power. A combining efficiency of over 80% was achieved from the output of a 69-element array.

(2) Measurements take with both the passive Phase I array and the active Phase II array confirmed that the input and output signals can be isolated from each other using orthogonal field polarizations. This is a necessary criterion for an OSPC amplifier to operate without oscillation.

(3) Both (a) the orthogonal isolation within each patch radiating element and (b) the coupling isolation between adjacent elements within the array are sufficiently high to prevent the array from oscillating with at least 13 dB of gain.

(4) Combining individual amplifiers into an array does not cause amplifier gain to be diminished. Thirteen-dB gain was achieved both with the single prototype amplifier on a test block and with 69 amplifiers in the array.

(5) Large, closed-horn structures with conducting walls that support waveguide modes cannot be used to combine output power from an ortho-linear array of amplifiers. In such horns, variations in amplifier gain across the array set up higher-order-mode resonances which must be attenuated.

(6) By using an absorber-lined horn structure, significant gain can be achieved without inducing higher-order modes and the resultant oscillation. This was demonstrated in the second of the three tests reported herein.

(7) From the test results obtained in this program, two essential criteria are necessary to realize the full potential of an OSPC amplifier: (a) The horn structure must produce uniform amplitude and phase field distribution to achieve maximum output power and efficiency, and (b) the horn structure must not support waveguide mode propagation.

(8) The proposed solution to satisfy the two essential criteria cited above is to replace the current horn structure with a true space-fed horn. The proposed space-fed approach employs a corrugated feedhorn and meniscus lens to produce uniform field distribution and relies on free-space propagation instead of guided-wave propagation. Tests using the absorber-lined feedhorn have shown that the absorber material along the wall attenuates higher-order mode propagation. In one test that partially emulated the proposed space-fed horn approach, 13-dB gain was achieved over a sizeable bandwidth without incurring oscillations.

6.0 RECOMMENDATIONS

On the basis of the results from the space-fed and absorber-lined feedhorn tests reported herein, it can be concluded that, by using a properly designed space-fed OSPC amplifier structure, (1) the power for the amplifier array can be combined effectively and efficiently, and (2) the array will not oscillate when surrounded by a non-reflective environment. The space-fed horn shown in Figure 23 of this report is superior to any of the configurations tested in terms of absorbing higher-order modes with minimal combining loss, and thus will allow the OSPC amplifier to work in a stable mode without producing oscillation. This novel space-fed horn design incorporates a transverse corrugated horn and a meniscus lens to achieve both (1) uniform field distribution to ensure high efficiency and (2) free space propagation (as opposed to waveguide propagation) to avoid reflecting fields that induce higher-order-mode oscillation.

The space-fed horn structure depicted in Figure 23 has already been designed, so the cost to build and evaluate the horn in the OSPC amplifier would be minimized. Also, the existing active array could be used with the new feedhorn without modification. Therefore, it is recommended that the space-fed horn be built, assembled with the present array to form a new OSPC amplifier, and tested to evaluate its performance.

APPENDIX A. OSPC Amplifier Test Plan

The test plan used to perform the amplifier tests is included here in Appendix A.

PREPARED BY	CAGE CODE 94756	NUMBER SCAR T01
J. Benet *J. Benet*	**Rockwell International Corporation**	TYPE Hardware
APPROVALS	**Defense Electronics**	DATE 2 September 1993
TSD		SUPERSEDES SPEC. DATED:
TSD	**TEST PLAN**	REV. LTR.
NASA		PAGE 1 of 8

TITLE

NASA SCAR
Orthomode Spatial Power Combiner (OSPC) Amplifier

1.0 Scope.
This document defines the plan to test the orthomode spatial power combiner (OSPC) amplifier that has been developed on the NASA SCAR Phase II program under contract NASW-4513.

2.0 Objective.
The objective is to provide data which will permit (1) the characterization of the SCAR Phase II OSPC Amplifier for power, gain, and stabilization (oscillation) characteristics and (2) a determination of whether an absorber-lined horn can effectively prevent oscillation.

3.0 Definitions.

3.1 Space-fed Amplifier.
The space-fed amplifier consists of a 69-element active amplifier array, a parasitic patch array, and a three-piece dielectric lens assembled together using the final section of the Phase II orthomode spatial power combiner. A ½-inch thick, toroidal ring is used to hold the lens in place. The orthomode transducer is mounted on an absorber-lined metal plate which is suspended approximately eight inches above the array by four threaded metal rods. The four rods also secure a phenolic ring to the final section of the Phase II horn.

3.2 Absorber-Lined Phase I Amplifier.
The Phase I horn, depicted in Figure 1, will be modified as follows. The longitudinal slots containing foam dielectric material at the mouth of the horn will be machined off to form a smooth wall. Approximately two-thirds of the wall from the mouth to the throat of the horn will then be lined with absorber material. The three-piece dielectric lens and the parasitic patch array will be assembled along with the active amplifier array to form an OSPC Amplifier.

3.3 Phase II OSPC Amplifier.
As shown in Figure 2, the Phase II OSPC Amplifier consists of the orthomode transducer (OMT), the Phase II longitudinally slotted horn, the three-piece dielectric lens, the parasitic patch array and the 69-element active amplifier array.

4.0 Standard Laboratory Practices.
All tests will be conducted in accordance with Tactical Systems Division's standard laboratory practices. These include (but are not limited to) the following practices.

Tests shall be conducted in a clean engineering laboratory in which food, drinks, and smoking are prohibited. The laboratory shall be maintained in an electrostatic discharge (ESD) free environment. Tests shall follow a written test plan. All data, events, dates and times of tests, and tests conditions shall be recorded in a standard laboratory notebook or recorded in computer memory for later print-out. In all cases the dates and conditions of the tests shall be included. All instrumentation equipment shall be calibrated. The manufacturer's model number and the Rockwell property number of the equipment used shall also be recorded. CRT display data shall be recorded by use of photographs. Each photograph shall also record the instrument settings. All requisite care and precautions shall be utilized to ensure safety and to protect equipment from damage.

5.0 Precautions.
Precautions shall be taken to avoid damaging the OSPC Amplifier. Potential damage risks are identified in the table below along with procedures which shall be implemented to eliminate the potential for damage.

Potential Damage Risk	Risk Avoidance Procedure
Excessive bias conditions could burn out the transistors in the array.	The array shall be biased with a voltage supply that has a gradual voltage control, such as the HP 6024A. Prior to biasing the array, the voltage supply setting shall be tested on an open circuit, and the current limiting shall be set to 10.5 amperes. The bias voltage shall be slowly increased from 0 to 8.5 volts. The bias voltage shall not exceed 8.5 volts under any conditions.
The OSPC Amplifier could be physically damaged during assembly.	The OSPC Amplifier and all of its components shall be assembled on a workbench that is covered with foam or other cushioning material.
Transistors in the array could be damaged from electrostatic discharge (ESD).	Work areas shall be checked for electrostatic material. Any material found shall be removed from the laboratory. Bonding tips used in assembly shall be grounded prior to bonding. Grounded wrist straps shall be used by personnel handling or testing the array.

6.0 Test Equipment.
The following test equipment is required to perform the tests described below. All equipment shall have a valid current calibration sticker.

1. Hewlett Packard 8510B, automatic network analyzer (ANA) with computer interface.
2. HP 6024A power supply.
3. Digital voltmeter.
4. Spectrum analyzer covering up to 18 GHz.
5. Spectrum analyzer camera with film.
6. RF power meter.
7. RF signal source/generator with output power adjustable up to one watt.

7.0 Tests.
The following tests shall be conducted: (1) space-fed amplifier gain test, (2) absorber-lined feedhorn test, and (3) OSPC oscillation test. Risk precaution procedures listed above shall be carried out in conjunction with the test procedures listed below.

7.1 Space-Fed Amplifier Gain Test.

7.1.1 Purpose.

The purpose of this test is to demonstrate the validity of the orthomode spatial power combiner concept by measuring the gain of the OSPC Amplifier array.

7.1.2 Approach.

The OSPC Amplifier will be configured as a space-fed amplifier as described in Section 3.1 to allow gain measurements to be taken in the absence of horn-induced oscillations. Measurements will be taken on a Hewlett Packard 8510B automatic network analyzer (ANA). Data from the analyzer will be sent to a computer and stored on disk so that the data can be plotted later in a report. The voltage will be set using an HP 6024A power supply and will be monitored on a digital voltmeter.

7.1.3 Test Procedure.

The following test procedure shall be used for this test. All recorded data shall reference the corresponding step number in the procedure (e.g., 7.1.3-6).

1. Calibrate the HP 8510B automatic network analyzer using full four-port error correction over the minimum frequency range from 16.0 to 17.5 GHz in steps of 10 MHz. APC-3.5 connectors shall be used.

2. Assemble the space-fed amplifier in accordance with Section 3.1 with the exception that the active array shall be replaced with the passive feed-through array (for the initial reference measurement).

3. Connect the assembly to the coaxial input and output ports of the network analyzer. Spanning the frequency range from 16.0 to 17.5 in steps of 10 MHz, measure and store the reference gain response of the space-fed horn with the passive array.

4. Replace the passive array with the active amplifier array, and connect the space-fed amplifier to the same ports of the network analyzer.

5. Set the current limit on the voltage supply to 10.5 amperes. Set the voltage supply to zero volts. Connect the bias leads to the array. Slowly raise the bias voltage from zero to 6.0 volts.

6. Record the voltage and current settings. Spanning the frequency range from 16.0 to 17.5 in steps of 10 MHz, measure the gain response and normalize that response to the stored reference measurement. Store the normalized response.

7. Slowly increase the bias voltage to 8.5 volts.

8. Record the voltage and current settings. Spanning the frequency range from 16.0 to 17.5 in steps of 10 MHz, measure the 8.5-volt gain response and normalize that response to the stored reference measurement. Store the normalized response.

7.1.4 Test Results.

Test results are expected to verify the nominal amplifier array gain of 11 dB at 6.0 volts and 10 dB at 8.5 volts. The stored data shall be plotted and placed in the written test report.

7.2 Absorber-Lined Feedhorn Test.

7.2.1 Purpose.

The purpose of this test is to demonstrate the validity of using absorber material in the feedhorn to simulate a free space environment, void of higher-order mode resonances. In this case the OSPC Amplifier should produce gain without oscillations.

7.2.2 Approach.

The OSPC Amplifier will be configured using the absorber-lined Phase I amplifier described in Section 3.2. The bias voltage will be raised while observing the spectrum analyzer for oscillations. If oscillations occur, the voltage and current level will be recorded and the spectrum analyzer display will be photographed, first at the voltage level corresponding to the onset of the oscillation and then at a bias of 8.5 volts. If no oscillations occur, a photograph of the spectrum analyzer will be taken to demonstrate the absence of oscillation. If oscillations do not occur, the gain of the amplifier with both the active and passive arrays will be measured on the HP 8510B, automatic network analyzer (ANA). Data from the network analyzer will be sent to a computer and stored on disk so that the data can be plotted later in a report. The voltage will be set using an HP 6024A power supply and will be monitored on a digital voltmeter.

7.2.3 Test Procedure.

The following test procedure shall be used for this test. All recorded data shall reference the corresponding step number in the procedure (e.g., 7.2.3-5).

1. Using the absorber-lined feedhorn described in Section 3.2, connect the output port from the orthomode transducer (OMT) to the spectrum analyzer. Terminate the input port of the OMT with a matched load.

2. Set the frequency range of the spectrum analyzer to cover 15.5 to 18 GHz.

3. Set the current limit on the voltage supply to 10.5 amperes. Set the voltage control to zero volts. Connect the bias leads to the array. Slowly raise the bias voltage from zero to 8.5 volts while observing the spectrum analyzer for oscillations.

4. If oscillation does not occur, proceed to step 7.

<u>Oscillation Observed With Terminated Input:</u>

5. Adjust the bias voltage to correspond to the onset of oscillation. Record the bias voltage and current, and photograph the spectrum analyzer display.

6. Then slowly raise the voltage to 8.5 volts. Record the voltage and current levels and photograph the spectrum analyzer display. Do not proceed further with the following tests.

<u>No Oscillations Observed With Terminated Input:</u>

7. Record the voltage and current levels, and photograph the spectrum analyzer display to provide evidence of no oscillation.

8. Remove the termination from the input port of the OMT, and attach the coaxial lead from the RF signal source. Adjust the signal level of the source to +11 dBm at 16.5 GHz. While observing

the spectrum analyzer, and with the bias voltage still set to 8.5 volts, slowly sweep the frequency from 16 to 18 GHz. Observe whether oscillations occur in the presence of the injected RF signal.

9. Record the voltage and current levels, and photograph the spectrum analyzer display to provide evidence of whether or not oscillation occur. Set the voltage supply to zero volts. If oscillations were observed, proceed no further with this procedure. If no oscillations were observed, proceed with the following steps.

No Oscillations Observed With Input Signals:

10. Calibrate the HP 8510B automatic network analyzer using full four-port error correction over the minimum frequency range from 16.0 to 17.5 GHz in steps of 10 MHz. APC-3.5 connectors shall be used. This step can be omitted if the ANA has been calibrated within the previous 4 hours. Record in the laboratory notebook whether the network analyzer was recalibrated.

11. Replace the active array in the absorber-lined feedhorn with the passive feed-through array (for the initial reference measurement). Connect the assembly to the coaxial input and output ports of the network analyzer.

12. Spanning the frequency range from 16.0 to 17.5 in steps of 10 MHz, measure and store the reference gain response of the absorber-lined feedhorn with the passive array.

13. Replace the passive array in the absorber-lined feedhorn with the active amplifier array. Connect the assembly to the coaxial input and output ports of the network analyzer.

14. Set the current limit on the voltage supply to 10.5 amperes. Set the bias voltage to zero. Connect the bias leads to the array. Slowly raise the bias voltage from zero to 6.0 volts.

15. Record the voltage and current settings. Using the calibration setup in Step 10, measure and store the gain response.

16. Normalize the gain response in Step 15 to the reference measurement in Step 12 and store the results.

17. Slowly increase the bias voltage to 8.5 volts and record the voltage and current settings. Measure and store the 8.5-volt gain response.

18. Normalize the gain response in Step 17 to the reference measurement in Step 12 and store the results.

7.2.4 Test Results.

The absence of oscillations will verify that the absorber-lined horn will prevent higher-order mode resonances and will lay the foundation for an improved space-fed horn approach using a meniscus lens and a corrugated horn to achieve high efficiency. Because there will be some OSPC Amplifier losses, the expected overall amplifier array gain should be less than 10 dB. However, the overall gain of the active amplifier should be approximately 10 dB higher than that of the passive array. The gain of the array normalized to the passive array should be approximately 11 dB at 6.0 volts bias and 10 dB at 8.5 volts bias. The presence of oscillations will show that the absorber material is inadequate to prevent higher-order mode resonances.

7.3 OSPC Oscillation Test.

7.3.1 Purpose.
The purpose of this test is to characterize the oscillation of the OSPC Amplifier. The test includes recording the oscillation spectrum, measuring the output power, and determining injection-locking properties.

7.3.2 Approach.
The OSPC Amplifier will be configured using the Phase II OSPC Amplifier described in Section 3.3. Measurements will be taken on a spectrum analyzer to verify the spectrum of oscillations. Photographs will be taken to record the spectrum analyzer display. Absolute power measurements will be recorded from an RF power meter. An RF signal will be injected into the OSPC Amplifier, and the frequency and input power will be varied to determine if it can be injection locked.

7.3.3 Test Procedure.
The following test procedure shall be used for this test. All recorded data shall reference the corresponding step number in the procedure (ie., 7.3.3-4).

1. Using the Phase II OSPC Amplifier described in Section 3.3. connect the output port from the orthomode transducer (OMT) to the spectrum analyzer. Terminate the input port of the OMT with a matched load.

2. Set the frequency range of the spectrum analyzer to cover 15.5 to 18 GHz.

3. Set the current limit on the voltage supply to 10.5 amperes. Set the voltage supply to zero volts. Connect the bias leads to the array.

4. Slowly raise the bias voltage from zero but do not exceed 8.5 volts. As soon as a single oscillation frequency first appears on the spectrum analyzer, do not further increase the bias voltage. Record the voltage and current settings, and photograph the spectrum analyzer display.

5. Connect the RF power meter to the output port of the OMT and record the meter reading.

6. Reconnect the output port to the spectrum analyzer and continue to raise the bias level to 8.5 volts maximum. If multiple oscillations occur simultaneously, back down the voltage to the point at which only one oscillation signal is present. Record the voltage and current settings, and photograph the spectrum analyzer display.

7. Connect the RF power meter to the output port of the OMT and record the meter reading.

8. If multiple oscillations did not occur, proceed with Step 10. Otherwise, reconnect the output port to the spectrum analyzer and continue to raise the bias level to 8.5 volts maximum. Record the voltage and current settings, and photograph the spectrum analyzer display.

9. Connect the RF power meter to the output port of the OMT and record the meter reading. Return the bias voltage to the level recorded in Step 6.

10. Reconnect the output port to the spectrum analyzer. Connect the RF signal source to the input port of the OMT. Set the source frequency 50 MHz away from the free-running oscillation (FRO) frequency of the OSPC Amplifier, and set the input source power level to 0 dBm.

11. While observing the spectrum analyzer, slowly increase the RF power level from the source until the source signal becomes visible on the spectrum analyzer. Record the voltage setting, the current settings, and the RF input signal power, and photograph the spectrum analyzer display.

12. Continue increasing the RF signal power level until the level of the oscillation signal drops by 1 dB. Record the voltage setting, the current settings, and the RF input signal power, and photograph the spectrum analyzer display.

13. Continue increasing the RF signal power level (but do not exceed 1 watt of power) until the free-running oscillation signal disappears. Record the voltage setting, the current settings, and the RF input signal power, and photograph the spectrum analyzer display.

14. Change the RF signal frequency to 100 MHz away from the FRO frequency. Remove the RF signal power to re-establish free-running oscillation, then set the RF input signal power level to 0 dBm. Repeat Steps 11, 12, and 13.

15. Keep repeating steps 11, 12, and 13, increasing the RF signal offset frequency by 100 MHz each time until there comes a point where the FRO does not disappear with one Watt of RF input power.

7.3.4 <u>Test Results.</u>

The results are expected to show that the minimum output power of the Phase II OSPC Amplifier will be somewhat less than 5 watts. The results will also determine the feasibility of using the OSPC Amplifier as an injection-locked oscillator. The amount of injection-locked gain and the bandwidth will be determined. The test results will be recorded and presented in the written report.

8.0 <u>Test Report</u>

A written report will be prepared containing a description of the tests that were conducted, the data including photographs and plots, and a summary of the results. The report will also include a conclusion section that shows the relationship of the results to the OSPC Amplifier design.

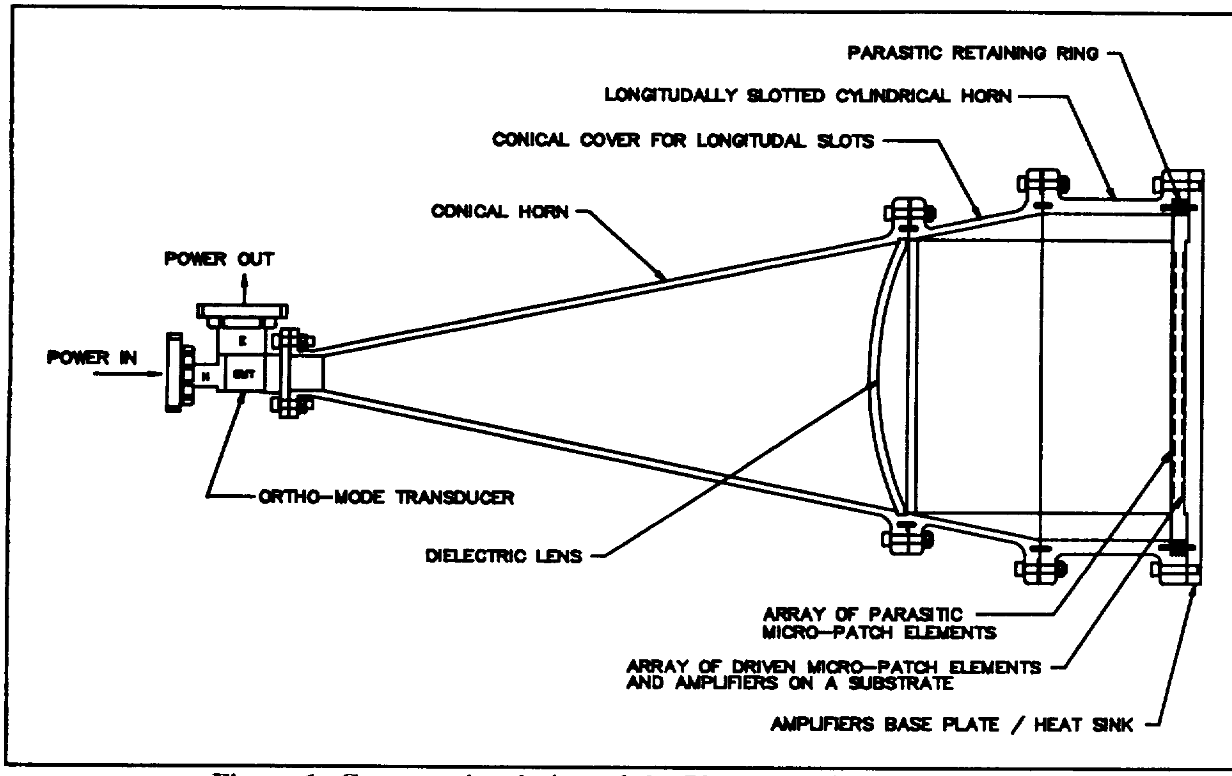

Figure 1 Cross-sectional view of the Phase I conical horn design

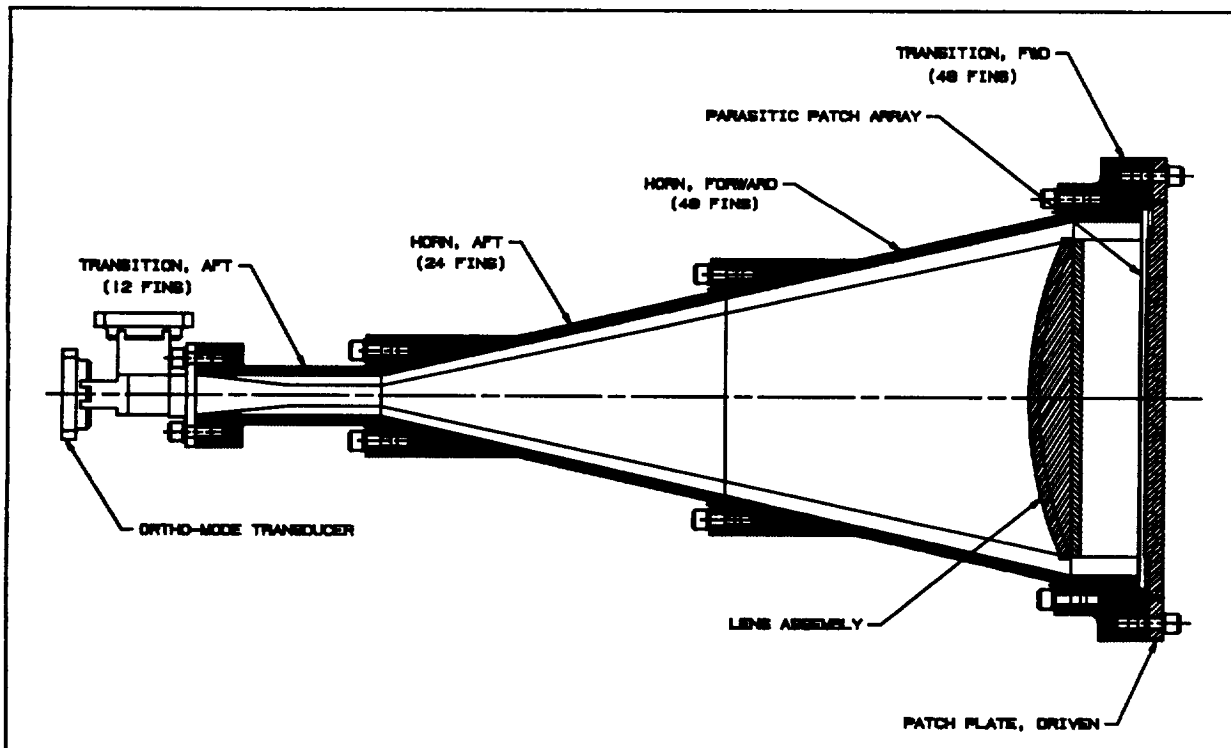

Figure 2 Cross-sectional view of the Phase II OSPC amplifier assembly.